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Wind Power Short-Term Forecasting System

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Abstract - The Romanian National Energy strategy is requesting that renewables quota to reach 33% of consumption in 2010 and 38% in 2020. One of the most challenging issues facing wind energy today is its maximal and reliable integration in the power markets. Due to transport / distribution grid lack of flexibility and high level of concentration in Dobrogea region of large wind developments the access to the grid in Romania is proving difficult. This paper explores the role of short-term forecasting of wind power in Dobrogea for the successful integration of large wind farm capacity (over 2,000 MW) into a single injection point.

Index Terms **– Forecasting, Network operating systems, Prediction methods, Wind power generation**

I. INTRODUCTION

Wind power has four characteristics that affect how it is integrated into systems: variability, near-zero variable cost, difficulty of forecasting precisely the output, and the remoteness. The ideal market structure for wind integration includes: a) larger balancing areas and more access to neighboring markets; b) a robust electric grid; c) shorter term generation markets; c) more flexibility in generation and load; d) wind forecasting effectively integrated into system operation; e) more flexible transmission services.

One of the largest problems of wind power is its dependence on the volatility of the wind. This behavior happens on all times scales, but two of them are the most relevant: one is for the turbine control itself (from ms to s) and the other one is important for the integration of wind power in the electrical grid, and therefore determined by the time constants in the grid (from minutes to weeks).

The following types of applications of wind prediction models can be identified:

-optimisation of the scheduling of the conventional power plants by functions such as economic dispatch. The prediction horizons can vary between 3-10 hrs depending on the size of the system and the type of conventional units included in the generation mix.

-optimisation of the value of produced electricity in the market. Such predictions are required by different type of end-users: utilities, TSO's, energy traders, power generators and for different functions as unit commitment, economic dispatch, dynamic security assessment, participation in the electricity market with the time scale of 0-48 hrs.

-additionally, even longer time scales would be interesting for the maintenance planning of large power plant components, wind turbines or transmission lines. The accuracy of weather predictions decreases strongly at 5-7 days in advance and such systems are only now starting to appear.

Up to 15 years of experience with different forecasting systems have been built up in some utilities in Germany, Denmark, Spain, Dutch, Ireland, Greece, Italy and some in USA and Australia have used forecasting now [1] - [10].

II. SHORT TERM PREDICTION – AN OVERVIEW

In general, the models can be classified as either involving a Numerical Weather Prediction model or not. Typically, prediction models using NWP forecasts outperform time series approaches after ca 3-6 hrs look-ahead time. Two different schools of thought exist related to short term prediction: the physical and the statistical approach.

Short term prediction of wind power for grid scheduling purposes was established in its current form including NWP-Numerical Weather Prediction ca 1990 by Risoe National Laboratory, Denmark. The model now called Prediktor was used operatively by some Danish TSO from 1993, while others started to use WPPT-Wind Power Prediction Tool. Denmark was the first country to get significant wind power development. Some German TSO's started to use short term prediction model ca 2000, using a model developed by ISET. The Spanish TSO have implemented the Sipereolico tool developed by the University Carlos III of Madrid. In Italy, GSE-Gestore dei Servizi Elettrici is using starting with 2007 a combination of neural network model and a physical one. In U.S.A., TSO's are using EWind an US - American model developed by TrueWind. 3Tier Environmental Forecast Group works with a nested NWP for Pacific NW. Garrad Hassan now has a forecasting model based on NWP forecasts from British MetOffice.

Currently, there is a wealth of models (>50) either at research or at commercial level. Two modes of operation can be distinguished: the models can be installed at the premises

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of the client and run operationally by the client or the model can be run by a service provider taking over the task of dealing with the prediction model and reporting the final results to the customer, often as email or web pages/services.

III. WIND PREDICTION MODEL IN ROMANIA

A research project regarding wind forecasting in Romania has been launched by C-Tech Romania and NEK Umwelttechnik AG in cooperation with Meteotest Switzerland. This project is related to wind energy developments in Dobrogea, a region in the eastern part of Romania, where Eolica Dobrogea Srl is developing 1,800 MW of wind power.

Wind speed and direction are measured at 14 masts in an area close to the Black Sea. The measurement height is between 40 m and 60 m. The availability of continuous measurements at several positions offers a good data base to evaluate wind forecasts for this region and to enhance forecast quality. Wind forecasts are simulated using the Weather Research and Forecasting (WRF) model.

The WRF model is a state-of-the-art numerical weather prediction system designed for a broad spectrum of applications. WRF is mainly developed at the National Center for Atmospheric Research (NCAR), U.S.A. and is in operational use at the National Centers for Environmental Prediction (NCEP). The model is designed for operational forecasting as well as for atmospheric research needs. It can be applied for a broad range of scales from meters to thousands of kilometers. WRF includes a variety of numerical methods and physical parameterizations that can be used according to the demand. A detailed description of the schemes is available on the WRF homepage (www.wrf-model.org).

The ability of WRF for high resolution simulations and the availability of different numerical and physical schemes make it a suitable tool for wind forecasts in different kinds of terrain and climates. A number of groups in Europe and the USA are using WRF for studies in the field of wind energy. It has proven to provide a good description of the mean wind and of the wind distribution.

IV. MODEL DESCRIPTION AND SET UP

The current project focuses on the forecast range 24 to 48 hours. Forecasts for a period of 60 hours are run every day starting at 12 UTC the previous day. A first evaluation of the model set-up has been performed in summer 2008. It was based on hindcasts for 11 periods in 2007 selected to be representative for typical wind situations in the Dobrogea region.

The orographic structure of the region is not very complex – height differences are in the range of few hundred meters – and there are no steep slopes. The vicinity to the coast line might affect the local wind field due to temperature and roughness changes between land and sea. Additionally, the land-sea difference might trigger local circulation systems like land-sea breezes. Still, the mast measurements do not show a pronounced sea breeze circulation in this region. On a more regional scale, the steering effect of the Carpathians causes high wind speeds known as "Carpathian Low Level Jet". Thus, the most important effects that need to be considered for a wind forecast in the region of Dobrogea are the land-sea contrast and the Carpathians.

The grid spacing of today's numerical weather prediction models are in the range of 10 km. In the nearest future weather forecasts with a grid spacing of 2–3 km will be available. Results at this resolution are a good basis for wind energy production forecasts. The resolution is certainly not high enough to capture all local effects -especially in complex terrain- but it is a good starting point for energy forecasts. Thus, a grid spacing around 3 km is favored for the WRF simulations.

The aforementioned requirements lead to a set-up that includes three model domains. A nested model simulation is suitable to fulfill both requirements: a coarse domain that includes the Carpathians and a smaller, inner domain with a higher resolution in order to have a more precise description of the coast line. The outermost domain with a grid size of 30 km is covering a big part of Eastern Europe (Fig. 1). The white frames mark the nested domains at 10 km and 3.3 km grid size as in figure 2.

The domain of 2400 km x 2100 km allows a good representation of synoptic scale features. The results of the outermost domain are used as boundary values for a nested domain with a grid size of 10 km (Fig. 2, left). This first nested domain has an extension of 970 km x 970 km and includes the Carpathian region. The innermost domain of about 440 km x 400 km with a horizontal grid spacing of 3.3 km covers the project area north of Constanta (Fig. 2, right). The white frame on the left hand side marks the position of the innermost domain.

Land-sea differences cause modifications of the vertical wind profile. These changes are important for the wind forecast at hub heights. The ability to reproduce the changes is affected by the turbulence parameterization and the vertical resolution. The turbulence parameterization used in the forecast model has proven to be an important impact parameter for the wind speed profile. Furthermore, a good vertical resolution in the lower part of the atmosphere is crucial. The current forecasts are using 8 levels in the lowest 1000 m of the atmosphere. The wind forecast model for the Dobrogea region was run once a day. Initial and boundary values are taken from the Global Forecast System GFS.

GFS is a global medium range forecasting system run by NOAA (USA). It is run four times a day and produces forecasts every three hours up to five days in advance. The horizontal grid spacing is 0.5^{o} (approximately 50 km) and 64 vertical layers are calculated. GFS results are prescribed at the lateral boundaries of the outermost domain. The simulation is performed for a period of 60 hours, starting at 12 UTC the previous day. The focus is on the second forecast day, which is the forecast period between 36 and 60 hours.

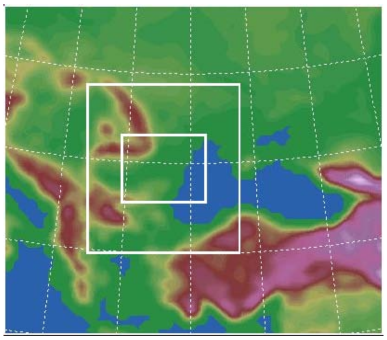

Fig.1. Outermost model domain with 30 km grid size

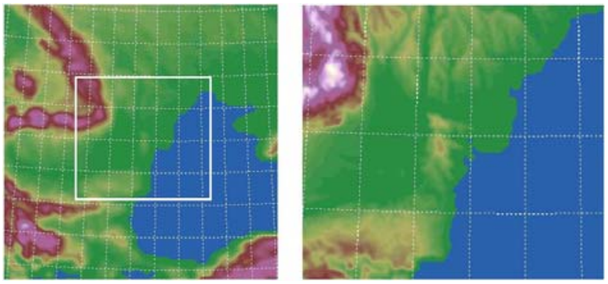

Fig. 2. Nested domains at 10 km grid size (left) and innermost domain at 3.3 km grid size (right).

The forecast results were displayed on a webpage as horizontal cross sections of hourly wind speed at about 50 m height (Fig. 3, left) and as time series of wind speed and direction at 40 m height for the nine mast positions (Fig. 3, right). Animated horizontal cross section of hourly wind speed at about 50 m height (left) and time series of wind speed and direction at 40 m height at the mast positions (right)

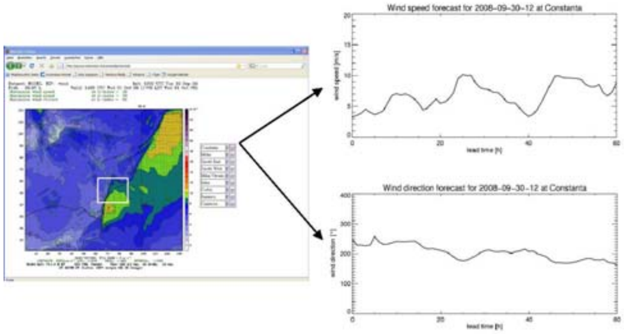

Fig. 3. Presentation of results on the webpage.

V. EVALUATION OF WIND AND ENERGY FORECASTS

Wind forecasts used for operational purposes need to be available every day at a certain time. The wind forecasts performed for the Dobrogea region had a poor availability in May because it took some time to adjust the system. The availability for the period June to September 2008 was 88%. The main reasons for delayed forecasts were difficulties with downloading the GFS data - partly because GFS data was provided too late by NOAA and partly because of data transfer rate. This shortcoming was solved by downloading GFS data every 6 hours and if the current data was delayed, data from 6 hours earlier was used. Thus, higher availability was achieved.

The wind forecasts for the months June to September 2008 are compared with measurements from nine masts in the Dobrogea region. Mast positions and measurement heights used for comparison are summarized in Table I.

TABLE I.
POSITIONS AND MEASUREMENTS HEIGHTS AT THE MASTS USED FOR COMPARAISON

Mast position	**Longitude/latitude [°]**	**Measurement heights (speed/direction) [m]**
Constanta	28.7 / 44.11	39.6 / 39.6
Midia	28.7 / 44.32	41.9 / 42.8
Sacele East	28.6 / 44.66	39.8 / 39.3
Sacele West	28.7 / 44.60	39.7 / 39.7
Mihai Viteazu	28.7 / 44.48	39.8 / 39.2
Istria	28.6 / 44.49	39.5 / 39.5
Corbu	28.6 / 44.42	39.3 / 39.3
Ramnicu	28.5 / 44.62	38.9 / 38.9
Casimcea	28.4 / 44.68	39.8 / 39.8

The comparison between results from numerical models and measurements has a fundamental shortcoming: model results represent the mean state of the atmosphere in a volume that is determined by the horizontal and vertical grid spacing, mast measurements, on the other hand, are point measurements representing a very small volume. The different representativity cannot be overcome and needs to be kept in mind when comparing the results. The WRF results are horizontally and vertically interpolated to the measurement position using a linear interpolation. The interpolated values are compared to measured wind speeds and directions.

The statistical evaluation is based on bias, root mean square error (RMSE) and mean absolute error (MAE) for wind speed. The measures are calculated for each position as an average value for the whole evaluation period (June to September 2008, Table II and Table III) and for every month for the first (and the second forecast day).

TABLE II.
BIAS, RMSE AND MAE OF WIND SPEED FOR THE FIRST FORECAST DAY (FORECAST PERIOD 12-36 HOURS) AVERAGED FOR THE WHOLE FORECAST PERIOD

	Con.	**Mid.**	**Sac.E**	**Sac.W**	**Mih.V.**	**Istria**	**Corbu**	**Ram.**	**Casi.**
Bias [m/s]	0.10	0.01	0.03	-0.04	-0.12	-0.51	-0.25	0.05	0.03
RMSE [m/s]	2.07	2.23	2.10	1.99	1.99	2.01	1.87	1.93	1.91
MAE [m/s]	1.68	1.84	1.73	1.63	1.63	1.64	1.53	1.56	1.54

The wind speed bias is small. Only Istria and Corbu show an underestimation of the average wind speed by 0.51 m/s (0.44 m/s) and 0.25 m/s (0.21 m/s) on the first (second) day, respectively. This underestimation corresponds to about 5% to 9% of the average wind speed.

The wind speed RMSE is very similar for the nine mast positions varying between 1.87 m/s and 2.23 m/s for the first forecast day and between 2.00 m/s and 2.30 m/s for the second forecast day. Nowadays wind forecasting systems based on weather forecasts plus post-processing achieve wind speed RMSE between 1.5 m/s and 2.5 m/s . Considering the fact that the results of this study are without further post-processing, the results are very satisfying.

TABLE III.
BIAS, RMSE AND MAE OF WIND SPEED FOR THE SECOND FORECAST DAY (FORECAST PERIOD 36-60 HOURS) AVERAGED FOR THE WHOLE FORECAST PERIOD

	Con.	Mid.	Sac.E	Sac.W	Mih.V.	Istria	Corbu	Ram.	Casi.
Bias [m/s]	0.17	0.04	0.12	0.04	-0.08	-0.44	-0.21	0.07	0.02
RMSE [m/s]	2.17	2.30	2.21	2.08	2.18	2.16	2.00	2.07	2.07
MAE [m/s]	1.78	1.89	1.79	1.69	1.76	1.76	1.62	1.67	1.67

The histogram of the wind speed RMSE of all mast positions (Fig. 4) shows that most of the RMSE values (50%) are between 1 and 2 m/s and about a third of the RMSE values are between 2 and 3 m/s. Another 10% of the values are between 3 and 4 m/s. Very low (below 1 m/s) and very high deviations (above 4 m/s) are rare. The histograms for wind speed RMSEs are very similar at the different mast positions. There are no indications that the wind speeds at some mast positions are predicted significantly better or worse than at others. At the mast positions Constanta, Midia and Sacele East RMSE values between 2 and 3 m/s are more frequent (nearly 40%) than at the other positions (about 30%). These positions, situated close to the sea, are also showing slightly higher average RMSE values than the other positions. A possible explanation is their vicinity to sea, since 3.3 km grid size might be not fine enough to describe the transition between land and sea accurately.

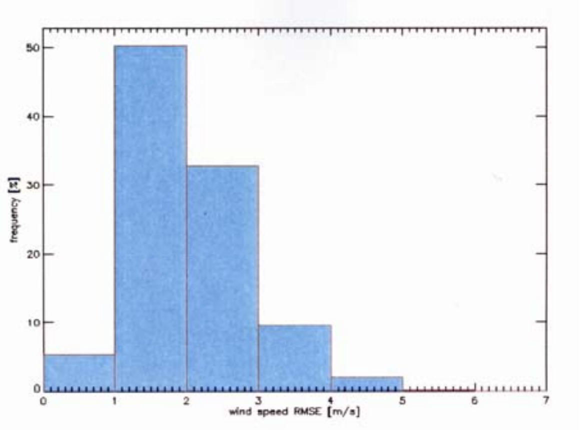

Fig. 4. The histogram of the wind speed RMSE of all mast positions

The RMSE values averaged for all stations for the single months differ by less than 10% (Tables IV and V). The histograms of RMSE values look similar for June and July, except for the fact that in June all RMSE values remain below 4 m/s. In August RMSE values between 2 and 3 m/s are significantly reduced. In September the portion of RMSE values below 3 m/s is reduced, while RMSE values above 3 m/s gain importance. Accordingly, wind speed RMSE's are highest in July and September (2.09 and 2.14 m/s on the first and 2.28 and 2.28 m/s on the second forecast day. But these are also the months with the highest average wind speeds. The relative RMSE values averaged for all stations are varying between 34% in September and 40% in June for the first forecast day and between 36% in September and 42% in June and July for the second forecast day. It seems that forecast quality in June, July and August is lower than in September. This is probably due to a lack of synoptic forcing in summer. This means that there is a tendency in summer in Romania to have more synoptic conditions with weak pressure gradients. Thus, meso-scale dynamics gain importance compared to situations with stronger synoptic forcing. To capture meso-scale dynamics correctly, small-scale initial conditions need to be accurate. Meso-scale details are not very well described in the GFS data. Thus, performance generally improves in seasons with strong synoptic forcing. The wind speed RMSE for the second forecast day is about 5–10% higher than for the first forecast day, resulting in relative RMSE values that are between 1% and 4% higher. This difference is similar for all months. The decrease of forecast quality with increasing forecast range is caused by growing uncertainty regarding the synoptic situation.

TABLE IV.
MONTHLY RMSE WIND SPEED AND RELATIVE RMSE AVERAGED FOR ALL STATIONS FOR THE FIRST FORECAST DAY (FORECAST PERIOD 12-36 HOURS)

	June	July	August	September
RMSE [m/s]	2.00	2.09	1.90	2.14
wind speed [m/s]	4.93	5.44	5.15	6.29
Relative RMSE [%]	40	38	37	34

TABLE V.
MONTHLY RMSE WIND SPEED AND RELATIVE RMSE AVERAGED FOR ALL STATIONS FOR THE SECOND FORECAST DAY (FORECAST PERIOD 36-60 HOURS)

	June	July	August	September
RMSE [m/s]	2.09	2.28	1.95	2.28
wind speed [m/s]	4.93	5.44	5.15	6.29
Relative RMSE [%]	42	42	38	36

Apart from the wind speed also the energy production is evaluated. There are no power production data available for the region of interest. Thus, evaluation is performed by comparison to a "virtual wind turbine". This means that power production is calculated from measured wind speed using the power curve of a wind turbine. The simulated power production is calculated from the simulated wind speed using the same power curve - in our case the power curve of an Enercon wind turbine. The wind data at 40 m height are used. The comparison does not show the real behavior of a wind turbine but mirrors a kind of idealized production. Still, it weights the forecast error depending on the wind speed range where it occurs. It takes into account that errors occurring below cut-in or above cut-off wind speed do not have any effect on the energy production, but in-between, small errors in wind speed can cause huge errors in power production.

The comparison of measured and simulated energy production is presented for the first forecast day in Table VI and for the second forecast day in Table VII. The statistical measures are the same as for wind speed: bias, RMSE and

MAE. It is common to measure the error of energy production forecast by weighting the error with the nominal power and, thus, get a relative error. Normalized MAE is remaining below 15% at all masts for the first forecast day. The forecast quality slightly decreases for the second forecast day, on average the normalized MAE of energy is increased by 1%.

TABLE VI.
RELATIVE BIAS, RELATIVE RMSE AND RELATIVE MAE OF WIND ENERGY PRODUCTION DERIVED FROM WIND SPEED BY USING THE POWER CURVE OF AN ENERCON WTG FOR THE FIRST FORECAST DAY (FORECAST PERIOD 12 – 36 HOURS) AVERAGED FOR THE WHOLE FORECAST PERIOD

	Con.	**Mid.**	**Sac.E**	**Sac.W**	**Mih.V.**	**Istria**	**Corbu**	**Ram.**	**Casi.**
Rel. Bias	0.01	0.01	0.01	0.01	0.00	-0.04	0.00	0.02	0.01
Rel. RMSE	0.17	0.19	0.17	0.16	0.17	0.17	0.16	0.17	0.16
Rel. MAE	0.13	0.14	0.13	0.12	0.12	0.13	0.12	0.12	0.12

TABLE VII.
RELATIVE BIAS, RELATIVE RMSE AND RELATIVE MAE OF WIND ENERGY PRODUCTION DERIVED FROM WIND SPEED BY USING THE POWER CURVE OF AN ENERCON WTG FOR THE SECOND FORECAST DAY (FORECAST PERIOD 36 – 60 HOURS) FOR THE WHOLE FORECAST PERIOD

	Con.	**Mid.**	**Sac.E**	**Sac.W**	**Mih.V.**	**Istria**	**Corbu**	**Ram.**	**Casi.**
Rel. Bias	0.01	0.01	0.02	0.01	0.00	-0.04	0.00	0.02	0.01
Rel. RMSE	0.18	0.20	0.18	0.17	0.19	0.19	0.17	0.18	0.17
Rel. MAE	0.14	0.15	0.14	0.13	0.14	0.14	0.12	0.13	0.12

VI. RELIABILITY OF THE PREDICTION MODEL

Two things need to be kept in mind when discussing the results. Firstly, the comparison is performed for a “virtual wind turbine” that does not display the real behavior of a wind turbine. The inaccuracy of calculating energy production from wind speed using a power curve is not included in this comparison. Secondly, the comparison is carried out using the WRF results without post-processing. If a forecast system for a specific site is developed, the first step is to get a reasonably good wind speed forecast from a weather forecast model. The second step is the consideration of small scale corrections based on dynamical downscaling (e.g. with a computational fluid dynamics model like WindSim) or statistical downscaling (e.g. model output statistics). This report shows the evaluation of the wind speed forecast from a weather forecast model without post-processing.

General statements about forecast quality can’t be given. The quality of forecast is strongly depending on the region, the orography. Forecasts for flat regions like e.g. Denmark are generally better than for locations in complex terrain. Also, prevailing meteorological situations are important. The evaluation presented in this report is performed mainly for summer season which is assumed to be more difficult to predict than autumn and winter.

Thus, the discussion of the evaluation of the results presented in this report and their comparison to other forecast systems is done in a qualitative way. Typical forecast errors for the average wind speed at 10 m height during the first 36 forecast hours are between 33–45% for the normalized RMSE. The values are confirmed by other studies. The normalized RMSE for the first forecast day shown in Table 4 is an average value for all stations. It is varying between 34% in September to 40% in June. Thus, the forecast of wind speed is in the range of other models.

The error of power production forecast based on a “virtual wind turbine” is compared with the results of operational wind power forecasting systems. A typical value of normalized MAE for nowadays wind power forecasting systems is about 20%. The evaluation results based on a “virtual wind turbine” that were presented in this report are significantly better (Fig. 5, Fig. 6).

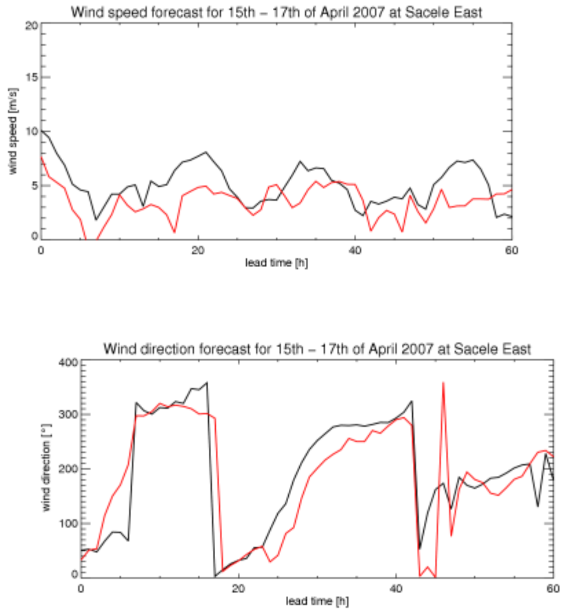

Fig. 5. Simulated and measured wind speed and direction for Sacele East

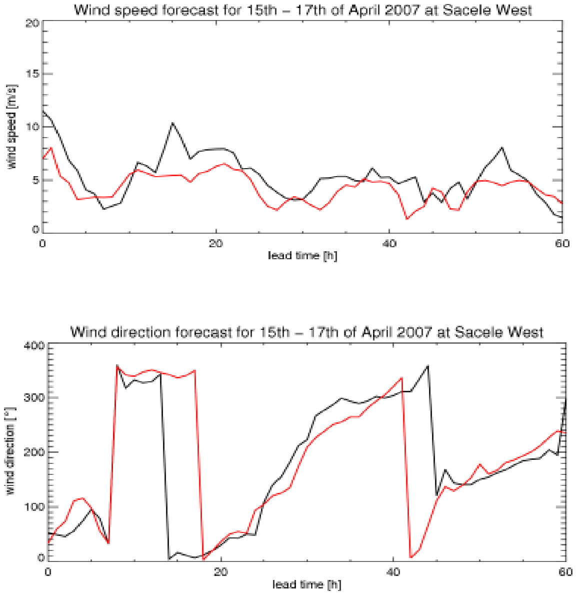

Fig. 6. Simulated and measured wind speed and direction for Sacele West

The normalized MAE does not exceed 15%. These are quite good results, but we need to keep in mind that this is not a comparison with the “real” behavior of a wind turbine.

VII. CONCLUSIONS

Daily wind forecasts are performed for Central Dobrogea region where wind energy developments of Eolica Dobrogea/Iberdrola take place. The forecasts are performed using the weather forecast model WRF. One mother domain and two nested domains are simulated using a grid size of 3.3 km in the innermost domain. The forecast period is 60 hours and the focus is on wind speed forecasts for the next day.

Forecast results are displayed as animated horizontal cross sections of wind speeds at 50 m and as time series of wind speeds and directions at the mast positions. The wind speed simulated with WRF is compared to measurements at around 40 m height. No post-processing was applied to the WRF results.

The model results are interpolated to mast positions and measurement heights. The interpolation -especially the linear, vertical interpolation - introduces errors. But measurement heights are close to a model level, so the effect is assumed to be small. Measured and simulated wind speeds are compared based on bias, mean absolute error (MAE) and root mean square error (RMSE).

The wind speed bias is very small. The small bias for the four months of forecasts shows that there is no systematic deviation.

The wind speed RMSEs are varying between 1.87 and 2.23 m/s for the first forecast day and between 2.00 and 2.30 m/s for the second forecast day. The RMSE values of nowadays forecasting systems (weather forecasts plus post-processing) are between 1.5 and 2.5 m/s. Considering that the wind forecasts in this study are run without post-processing, the results are very satisfying. This kind of error could be reduced by applying a dynamical downscaling or a statistical post-processing.

The energy production forecast is evaluated using a “virtual wind turbine” calculated from measured wind speed and a power curve. This “virtual wind turbine” does not display the real behavior, but is a substitute as long as real energy production data are missing. The comparison with results of operational wind power forecasting systems is just a very rough comparison and, additionally, the result quality strongly depends on the wind farm. Still, a typical value of the normalized MAE of nowadays operational forecast systems is about 20%. The normalized MAE of energy production in our study remains below 15%.

In conclusion, the forecast quality for wind speed is in the range of other forecast systems. No systematic deviations – constant under-or overestimation of wind speed – occur. This indicates that he model set-up is suitable for wind forecasts in this region. The similarity of forecast quality at all positions indicates that deviations are mainly caused by not capturing the synoptic situation properly and less by local influences and meso-scale dynamics. Only at the positions Constanta, Midia and Sacele there are indications that the model resolution is not high enough to describe the land-sea difference accurately.

VIII. OUTLOOK

The evaluation results suggest that the main source of errors is an insufficient description of the synoptic situation and, possibly, at the positions close to the sea the insufficient captured land-sea contrast. Possible post-processing methods are dynamical refinement or statistical post-processing methods.

The relatively homogenous forecast quality at the positions indicates that errors are not mainly caused by local effects or meso-scale dynamics. Thus, dynamical refinement might be able to improve the forecast at the positions close to the sea but would not improve deficiencies in the description of the synoptic situation.

One possibility of improving this shortcoming is running an ensemble system which means running the same forecasts using different initial and boundary data and different model set-ups. The advantage is that uncertainties arising from boundary values as well as the model setup are taken into account and that information about the uncertainty of the simulation is provided. The disadvantage is that it is very costly. Another approach is a statistical post-processing. Model output statistics (MOS) are a promising method to correct systematic errors of the wind forecast. In order to build a MOS system at least one year of measurements and simulation data need to be available. The MOS does not just correct systematic deviations of the wind forecasts, but also gives an indication about the uncertainty of the forecast.

IX. THE LESSONS LEARNED AND FUTURE DEVELOPMENTS

The Romanian TSO has decided that a new 400 kV station with some 2,000 MVA to be built in Tariverde. In station would be collected the most important developers from around some 250 sqkm. Therefore, the provision of short term prediction can be quite critical in terms of operational applications. It is obvious that for critical applications it is important to have reliable and well tested prediction systems.
The prediction system presented in this paper and the future plans related to the refinement can greatly influence the decisions making process of the TSO regarding the operational aspects and the access of the client of the DAM trading platform.

X. ACKNOWLEDGMENT

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XII. BIOGRAPHIES

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